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Patentanmeldung Nr. | Patent application No. | Demande de brevet n°

00202960.1

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
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Anmeldung Nr
Application no
Demande n°

00202960.1

Anmeldetag
Date of filing
Date de dépôt

25/08/00

Anmelder
Applicant(s)
Demandeur(s)

ASM LITHOGRAPHY B.V.
5503 LA Veldhoven
NETHERLANDS

Bezeichnung der Erfindung
Title of the invention
Titre de l'invention

Lithographic projection apparatus

In Anspruch genommene Prioriat(en) / Priority(ies) claimed / Priorite(s) revendiquée(s)

Staat State Pays	Tag Date Date	Aktenzeichen File no Numéro de dépôt

Internationale Patentklassifikation
International Patent classification
Classification internationale des brevets

/

Am Anmeldetag benannte Vertragstaaten
Contracting states designated at date of filing AT/BE/CH/CY/DE/DK/ES/FI/FR/GB/GR/IE/IT/LI/LU/MC/NL/PT/SE/TR
Etats contractants designes lors du depôt

Bemerkungen
Remarks
Remarques

"Lithographic Projection Apparatus"

The present invention relates to a lithographic projection apparatus. More particularly, the invention relates to a radiation sensor for use in a lithographic projection apparatus comprising:

- a radiation system for supplying a projection beam of radiation;
- a mask table for holding a mask;
- a substrate table for holding a substrate;
- a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate.

An apparatus of this type can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the mask (reticle) may contain a circuit pattern corresponding to an individual layer of the IC, and this pattern can then be imaged onto a target area (die) on a substrate (silicon wafer) which has been coated with a layer of photosensitive material (resist). In general, a single wafer will contain a whole network of adjacent dies which are successively irradiated through the reticle, one at a time. In one type of lithographic projection apparatus, each die is irradiated by exposing the entire reticle pattern onto the die in one go; such an apparatus is commonly referred to as a waferstepper. In an alternative apparatus — which is commonly referred to as a step-and-scan apparatus — each die is irradiated by progressively scanning the reticle pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the wafer table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed v at which the wafer table is scanned will be a factor M times that at which the reticle table is scanned. More information with regard to lithographic devices as here described can be gleaned from International Patent Application WO 97/33205.

Up to recently, apparatus of this type contained a single mask table and a single substrate table. However, machines are now becoming available in which there are at

least two independently movable substrate tables; see, for example, the multi-stage apparatus described in International Patent Applications WO 98/28665 and WO 98/40791. The basic operating principle behind such multi-stage apparatus is that, while a first substrate table is underneath the projection system so as to allow exposure of a first substrate located on that table, a second substrate table can run to a loading position, discharge an exposed substrate, pick up a new substrate, perform some initial alignment measurements on the new substrate, and then stand by to transfer this new substrate to the exposure position underneath the projection system as soon as exposure of the first substrate is completed, whence the cycle repeats itself; in this manner, it is possible to achieve a substantially increased machine throughput, which in turn improves the cost of ownership of the machine.

Lithographic apparatus may employ various types of projection radiation, such as ultra-violet light (UV), extreme UV, X-rays, ion beams or electron beams, for example. Depending on the type of radiation used and the particular design requirements of the apparatus, the projection system may be refractive, reflective or catadioptric, for example, and may comprise vitreous components, grazing-incidence mirrors, selective multi-layer coatings, magnetic and/or electrostatic field lenses, *etc*; for simplicity, such components may be loosely referred to in this text, either singly or collectively, as a "lens". The apparatus may comprise components which are operated in vacuum, and are correspondingly vacuum-compatible. As mentioned in the previous paragraph, the apparatus may have more than one substrate table and/or mask table.

In lithographic projection apparatus it is generally desirable to examine various aspects of the projection beam such as a dose (i.e. the total radiation energy per unit area delivered during an exposure), a focal plane position, uniformity of the beam, radiation distribution in a pupil plane of the projection system, etc. In addition, one may want to determine deviations of the projection beam introduced by the projection system, these deviations being referred to as aberrations. Examples of such aberrations are curvature of field, coma, astigmatism, spherical aberration, third and fifth order distortions, etc. In order to determine aforementioned beam aspects and aberrations, a radiation sensor for detecting radiation may be employed in the lithographic projection apparatus.

The present invention is concerned with radiation having wavelengths shorter than 50 nanometers. An example of such radiation is extreme ultraviolet (EUV) with wavelengths typically in the range of 10 to 15 nanometers. A major problem encountered in lithographic apparatus using such radiation is the generally strong absorption of the said

radiation by solid materials, liquids and gases, whereby the intensity of the projection beam can diminish completely. Consequently, a radiation sensor capable of detecting said radiation cannot partially or completely comprise such a strongly absorbing material in the radiation path. Another drawback is that existing radiation sensors for detecting radiation having wavelengths shorter than 50 nm, such as photomultiplier tubes, gas chambers, etc. - commonly used in synchrotrons - have dimensions that are far too large for use in a lithographic projection apparatus. Such existing sensors may further dissipate too much heat, possibly leading to undesirable temperature variations of the said sensor and/or of its surrounding environment (e.g. the substrate, an interferometry mirror block which is part of the substrate table, etc.).

It is an object of the present invention to provide a lithographic projection apparatus wherein a radiation sensor is conveniently positioned, said radiation sensor being capable of detecting radiation having a wavelength less than 50 nm.

According to the present invention there is provided a lithographic projection apparatus as specified in the opening paragraph, characterized in that the apparatus further comprises a radiation sensor which is located so as to be able to receive radiation out of the projection beam, said sensor comprising:

- a radiation-sensitive layer which converts incident radiation of wavelength λ_1, whereby $\lambda_1 < 50$ nm, into secondary radiation;
- sensing means capable of detecting said secondary radiation emerging from said layer.

Said secondary radiation can comprise electromagnetic radiation or electrons, for example.

In a preferred radiation sensor, secondary radiation comprises electromagnetic radiation with wavelengths lying in the range of visible light. In an alternative radiation sensor, the radiation-sensitive layer is covered with a protecting layer in order to protect said radiation-sensitive layer from deterioration by, for example, oxidizing gases or plasma etching (said deterioration leading to partial or complete incapability to convert incoming EUV radiation with wavelength λ_1 into said electromagnetic radiation). Further, said protecting layer can subsequently be at least partially covered by a patterned layer, generally comprising a metal e.g. chrome. Such a patterned layer can be useful when the sensor is applied for image analysis, as explained later hereunder.

Another preferred radiation sensor comprises a radiation-sensitive layer which converts incoming EUV radiation into electrons, the electrons emitted from said radiation-sensitive layer being at least partially collected by a conducting plate. Said plate can be positively charged. In another preferred radiation sensor, (electrical) charging in the radiation-sensitive layer caused by radiation-induced electron emission is electrically compensated, leading to a measurable compensatory electrical current. This concept of electrical compensation can also be employed in an array of lines comprising radiation-sensitive layers, whereby the current in each individual line can be separately measured; such a construction has advantages which will be explained later hereunder.

The invention also relates to a device manufacturing method comprising the steps of:

(a) providing a substrate which is at least partially covered by a layer of radiation-sensitive material;

(b) providing a mask which contains a pattern;

(c) using a projection beam of radiation having wavelength λ_1, whereby $\lambda_1 < 50$ nm, to project an image of at least part of the mask pattern onto a target portion of the layer of radiation-sensitive material.

characterized in that attendant to step (c), use is made of a radiation sensor to detect radiation out of the projection beam, said sensor comprising:

- a radiation-sensitive layer which converts incident radiation of wavelength λ_1 into secondary radiation;
- sensing means capable of detecting said secondary radiation emerging from said layer.

In a manufacturing process using a lithographic projection apparatus according to the invention, a pattern in a mask is imaged onto a substrate which is at least partially covered by a layer of energy-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, *e.g.* an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, *etc.*, all

intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, *etc*. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4.

Although specific reference has been made hereabove to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, *etc*. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion", respectively.

The invention and its attendant advantages will be further elucidated with the aid of exemplary Embodiments and the accompanying schematic drawings, whereby:

Figure 1 schematically depicts a lithographic projection apparatus according to the invention;

Figure 2 is a diagram of a radiation sensor according to a first embodiment of the present invention;

Figure 3 schematically depicts a radiation sensor according to a second embodiment according to the invention;

Figure 4 is a schematic representation of a radiation sensor according to a third embodiment of the present invention, and

Figure 5 schematically depicts a radiation sensor according to a fourth embodiment of the invention.

In the various drawings, like parts are indicated by like references.

Embodiment 1

Figure 1 schematically depicts a lithographic projection apparatus according to the invention. The apparatus comprises:

- a radiation system LA, IL for supplying a projection beam PB of radiation (*e.g.* EUV radiation);
- a first object table (mask table) MT for holding a mask MA (*e.g.* a reticle), and connected to first positioning means PM for accurately positioning the mask with respect to item PL;
- a second object table (substrate or wafer table) WT for holding a substrate W (*e.g.* a resist-coated silicon wafer), and connected to second positioning means PW for accurately positioning the substrate with respect to item PL;
- a projection system PL (a mirror group comprising 4, 5 or 6 mirrors, for example) for imaging an irradiated portion of the mask MA onto a target portion C (die) of the substrate W.

The radiation system comprises a source LA (*e.g.* a wiggler/undulator situated around the path of an electron beam in a storage ring or synchrotron, a plasma source etc.) which produces a beam of radiation. This beam is caused to traverse various optical components comprised in illuminator IL, — *e.g.* beam shaping optics, an integrator and a condensor — so that the resultant beam PB has a desired shape and intensity distribution in its cross-section.

The beam PB subsequently intercepts the mask MA which is held in a mask holder on a mask table MT. Having traversed the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto a target portion C of the substrate W. With the aid of the interferometric displacement measuring means IF, the substrate table WT can be moved accurately by the second positioning means PW, *e.g.* so as to position different exposure areas C in the path of the beam PB. Similarly, the first positioning means PM can be used to accurately position the mask MA with respect to the path of the beam PB, *e.g.* after mechanical retrieval of the mask MA from a mask library or during a scan. In general, movement of the object tables MT, WT will be realized with the aid of a long-stroke module (course positioning) and a short-stroke module (fine positioning), which are not explicitly depicted in Figure 1. In the case of a waferstepper (as opposed to a step-and-scan apparatus)

the mask table may be connected only to a short-stroke positioning device, to make fine adjustments in mask orientation and position, or the mask table may be fixed.

The depicted apparatus can be used in two different modes:

- In step mode, the mask table MT is fixed, and an entire mask image is projected in one go (*i.e.* a single "flash") onto a target portion C. The substrate table WT is then shifted in the x and/or y directions so that a different target portion C can be irradiated by the (stationary) beam PB;
- In scan mode, essentially the same scenario applies, except that a given target portion C is not exposed in a single "flash". Instead, the mask table MT is movable in a given reference direction (the so-called "scan direction", *e.g.* the y direction) with a speed v, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed $V = Mv$, in which M is the magnification of the projection system PL (typically, $M = 1/4$ or $1/5$). In this manner, a relatively large target portion C can be exposed, without having to compromise on resolution.

In order to be able to determine, for example, the dose at substrate level, a radiation sensor can be located at a convenient position, e.g. in the vicinity of the substrate. A preferred embodiment of such a radiation sensor is shown in Figure 2A. This sensor 9 comprises a radiation-sensitive layer 1 and sensing means. When EUV radiation of wavelength λ_1 hits said radiation-sensitive layer 1, this radiation can either be converted into secondary electromagnetic radiation having wavelength λ_2 or into lattice vibrations of said layer. To improve the ability to emit secondary radiation a rather complex material is employed, wherein said material generally comprises a host lattice (*e.g.* calcium sulfide (CaS), zinc sulfide (ZnS) or yttrium aluminum garnet (YAG)) and at least one ion such as Ce^{3+}, Ag^{+}, Al^{3+}, etc. The said ions are generally distributed in relatively small quantities in the host lattice. An example of a notation of such a material is CaS:Ce, whereby CaS is the host lattice, in which Ce^{3+} ions are distributed. Materials suitable for use in said layer 1 can be selected from the group comprising: CaS:Ce, YAG:Ce and ZnS:Ag,Al. The thickness of such a layer is preferably smaller than 1 μm. Such layers are capable of converting EUV radiation into secondary radiation with wavelength λ_2 which differs from the wavelength of the incident beam; generally, λ_2 lies in the range of visible light or in the range of ultraviolet light. This secondary radiation emerges from said layer 1 in all directions. Generally, layer 1 can be

provided upon a layer 3 – serving to bear layer 1 - comprising a material (*e.g.* quartz or CaF_2) through which radiation with wavelength λ_2 is transmitted, whereby it is ensured that layer 1 is located so as to be able to receive EUV radiation out of the projection beam. At least part of said secondary radiation is subsequently collected by the said sensing means which is sensitive to this radiation. An example of such sensing means may comprise collection optics 5 and a silicon diode 7. Said optics 5 may comprise one or more lenses capable of directing emerging secondary radiation to said diode 7.

The radiation sensor can also be employed as (part of) an image sensor with which it is possible to detect EUV radiation of wavelength λ_1 in order to be able to, for example, align a reference position on the mask to a reference position on the substrate; such alignment may be performed with nanometer accuracy. Furthermore, the said EUV radiation may be detected for analysis of different aspects of the projection beam such as a focal plane position of the projection system, uniformity of the beam, radiation distribution in the pupil plane of the projection system, etc. Said aspects can be determined using a transmission image sensor (TIS), for example. An example of such a TIS is described in US 4,540,277, incorporated herein by reference. Also deviations of the projection beam introduced by the projection system can be determined with said radiation sensor, these deviations being referred to as aberrations. Examples of such aberrations are curvature of field, coma, astigmatism, spherical aberration, third and fifth order distortions, etc. More information on measuring of said aberrations can be gleaned from European Patent Application 00301420.6 (P-0174), incorporated herein by reference.

An example of such an image sensor is shown in Figure 2B and is characterized in that a radiation sensor (as described in the previous paragraph) is provided with a metal layer 6 (*e.g.* a chrome layer) in which a certain pattern (*e.g.* a grid-like set of lines) is etched. In order to protect the radiation-sensitive layer 1 from the process steps involved to provide said metal layer with said pattern (*e.g.* by plasma etching), a protecting layer 8 is provided. This protecting layer 8 is located juxtapositionally with the said radiation-sensitive layer 1 on its radiation-receiving side, and its thickness is chosen so as to absorb only a small amount of incident radiation, ensuring enough transmission for accurate detection of EUV radiation. The thickness of such a layer 8 may lie in the order of 20 nm. Said protecting layer 8 may be selected from the group comprising, for example, diamond-like carbon (C), boron nitride (BN), silicon nitride (Si_3N_4), silicon carbide (SiC), B, Ru and

Rh and compounds and alloys thereof. Subsequently, the patterned metal layer 6 is provided on the radiation-receiving side of, and juxtaposed with, said protecting layer 8.

Embodiment 2

In a second embodiment of the invention, which may be the same as the first embodiment save as described below, the radiation sensor is characterized by converting the incident EUV radiation into secondary electrons. Electrons can be generated by two different processes. In a first process incident radiation hits a radiation-sensitive layer with a certain energy. Part of this energy may be used to ionize an atom or ion in the radiation-sensitive layer. The remaining energy – the energy difference between the energy of the incident radiation and the ionization energy of the atom or ion (also referred to as the binding energy of an electron) – is converted at least partially into kinetic energy which enables the electron to leave the ion or atom, and said electrons may eventually leave the radiation-sensitive layer. These electrons are referred to as electrons generated by the photo-electric effect.

In a second process, electrons can be generated by the so-called Auger effect. In this case, one electron relaxes to a lower energy level within an atom or ion, whereby the respective relaxation energy can be transferred to a second electron. If this relaxation energy is larger than the binding energy of the second electron, this electron will have a certain kinetic energy and will be able to leave the ion or atom and eventually may be able to leave the radiation-sensitive layer. Electrons generated by either the photo-electric or the Auger effect emerge randomly out of the radiation-sensitive layer. Since an atom or ion comprises one or more electrons having different binding energies, electrons emerge from the said layer with a large range of kinetic energies.

The radiation sensor 19 comprises a radiation-sensitive layer 11 and a sensor means 12 as shown in Figure 3. The radiation-sensitive layer 11 is able to convert incident EUV radiation into electrons generated by one of said processes. Said layer 11 preferably comprises a metal, for example.

The sensor means 12 - located so as to be able to receive at least part of the generated electrons - comprises a conducting plate 13 and a current-measuring means 15 which is connected to ground 17. Once electrons – independent of their kinetic energy - hit a conducting plate 13 an electrical current is induced which can be measured by the current-measuring device 15; this current is a measure of the number of incoming electrons which in

turn is a measure of the intensity (energy dose) of the incident EUV radiation. The plate 13 preferably comprises an electrically conducting material, *e.g.* a metal.

When electrons leave the radiation-sensitive layer 11, this layer 11 will be charged positively. Such a positively charged layer may attract negatively charged electrons. Electrons may eventually not be able to leave the said layer 11 and, consequently, may not reach the sensor means 12. Therefore, charging of the radiation-sensitive layer 11 must be electrically compensated, e.g. by connecting layer 11 to a ground or by negatively biasing said radiation-sensitive layer 11. Additionally, the conducting plate 13 can be positively charged (or biased) so as to selectively attract and accelerate electrons emerging from the radiation-sensitive layer 11.

Embodiment 3

In a third embodiment of the invention, which may be the same as the first embodiment save as described below, the radiation sensor is also characterized by converting the incident EUV radiation into secondary electrons. A radiation sensor 27 is depicted in Figure 4 and comprises a radiation-sensitive layer 21, *e.g.* a metal, and a sensor means 23 which is connected to ground 25. Analogous to the previous embodiment, the radiation-sensitive layer 21 is able to generate electrons according to similar processes. The electrons thus generated create a positively charged layer 21 which, upon connection to ground 25, will be electrically compensated, eventually giving a neutral layer 21. The resulting electrical current can be measured by sensor means 23, the current being a measure of the intensity of the incident EUV radiation. With such a radiation sensor 27 it is possible to determine, for example, the dose at substrate level when said sensor 27 is located in the vicinity of the substrate. The determination of said dose is not limited to the substrate level but can also be determined at other positions in the lithographic projection apparatus; for example, the dose of radiation hitting a lens element (*e.g.* a mirror) of the projection lens comprising a metal, for example, can also be determined.

Embodiment 4

Another preferred embodiment of the invention, which may be the same as the first embodiment save as described below, is a radiation sensor 37 - depicted in Figure 5 - which employs an array of lines 31, whereby each line 31 comprises radiation-sensitive material. The radiation-sensitive material in each line can generate and release electrons resulting in positively charged lines. By connecting each line to ground 35, the current needed to compensate the said charge in each individual line can be separately measured by sensor means 33. In this way, it is possible to discriminate between the dose of incoming radiation in each line, making it possible to determine, for instance, the uniformity of the projection beam.

Whilst we have described above specific embodiments of the invention it will be appreciated that the invention may be practiced otherwise than described. The description is not intended to limit the invention.

CLAIMS:

1. A lithographic projection apparatus comprising:

- a radiation system for supplying a projection beam of radiation having a wavelength λ_1, whereby $\lambda_1 < 50$ nm;
- a mask table for holding a mask;
- a substrate table for holding a substrate;
- a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate;

characterized in that the apparatus further comprises a radiation sensor which is located so as to be able to receive radiation out of the projection beam, said sensor comprising:

- a radiation-sensitive layer which converts incident radiation of wavelength λ_1 into secondary radiation;
- sensing means capable of detecting said secondary radiation emerging from said layer.

2. An apparatus according to claim 1 wherein said secondary radiation comprises electromagnetic radiation of wavelength λ_2, whereby $\lambda_2 > \lambda_1$.

3. An apparatus according to claim 2 wherein said radiation-sensitive layer comprises a compound selected from the group comprising: CaS:Ce, YAG:Ce and ZnS:Ag,Al.

4. An apparatus according to claim 1 wherein said secondary radiation comprises electrons.

5. An apparatus according to claim 4 wherein said secondary radiation comprises electrons selected from the group comprising:

- electrons generated by the photo-electric effect;
- electrons generated by the Auger effect.

6. An apparatus according to claim 4 wherein said sensing means is positively charged so as to selectively attract and accelerate electrons emerging from said radiation-sensitive layer.

7. An apparatus according to claim 4 wherein said radiation sensor comprises:

- an array of lines, each line comprising a radiation-sensitive material;
- a sensor means capable of separately detecting electrons leaving each individual line.

8. An apparatus according to claims 4 to 7 wherein said radiation-sensitive layer comprises a metal.

9. A device manufacturing method comprising the steps of:

(a) providing a substrate which is at least partially covered by a layer of radiation-sensitive material;

(b) providing a mask which contains a pattern;

(c) using a projection beam of radiation having wavelength λ_1, whereby $\lambda_1 < 50$ nm, to project an image of at least part of the mask pattern onto a target portion of the layer of radiation-sensitive material.

characterized in that attendant to step (c), use is made of a radiation sensor to detect radiation out of the projection beam, said sensor comprising:

- a radiation-sensitive layer which converts incident radiation of wavelength λ_1 into secondary radiation;
- sensing means capable of detecting said secondary radiation emerging from said layer.

10. A device manufactured in accordance with the method of claim 9.

ABSTRACT:

"Lithographic projection apparatus"

A lithographic projection apparatus comprising:

- a radiation system LA, IL for supplying a projection beam PB of radiation having a wavelength λ, whereby $\lambda < 50$ nm;
- a mask table MT for holding a mask MA;
- a substrate table WT for holding a substrate W;
- a projection system PL for imaging an irradiated portion of the mask MA onto a target portion C of the substrate W,

whereby the apparatus further comprises a radiation sensor which is located so as to be able to receive radiation out of the projection beam, and said sensor comprises:

(d) a radiation-sensitive layer, which converts incident radiation of wavelength λ into secondary radiation;

- sensing means capable of detecting said secondary radiation emerging from said layer.

Fig. 2A.

Fig.1.

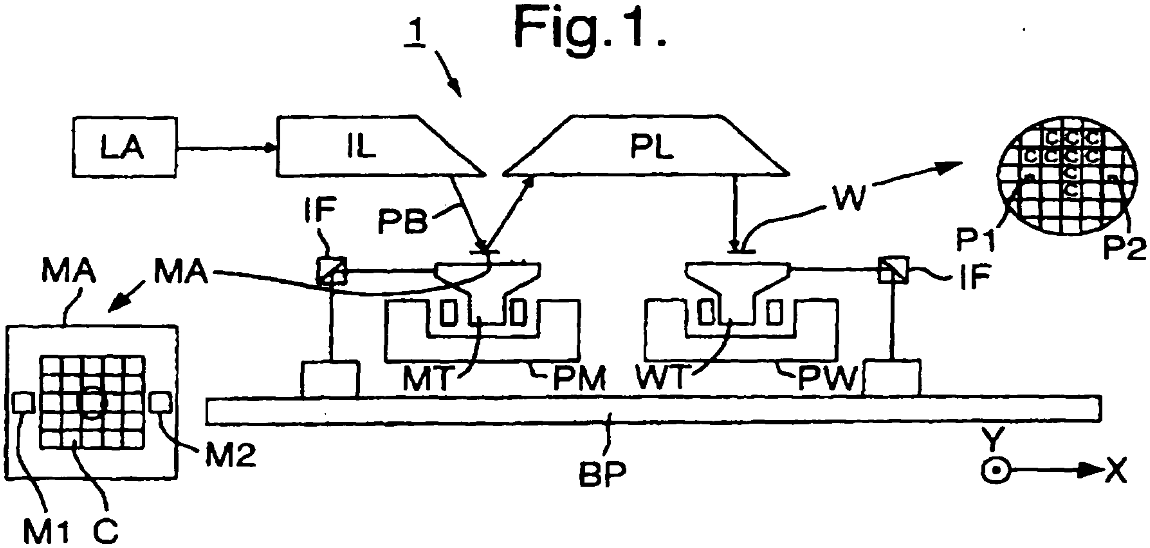

Figure 2A

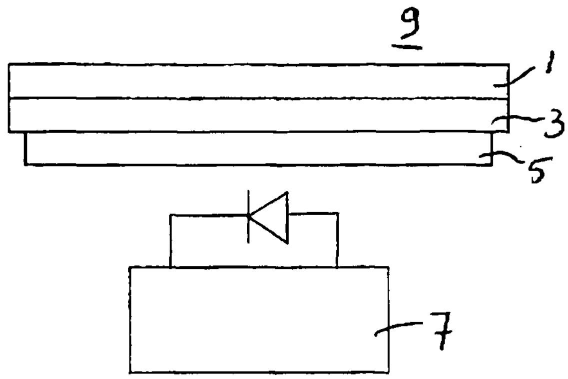

Figure 2B

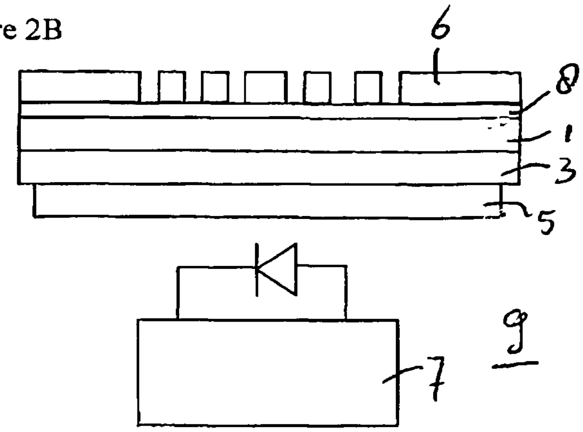

Figure 3

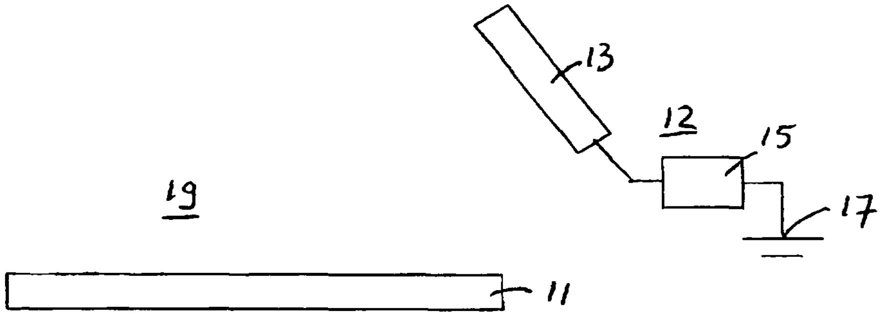

Figure 4

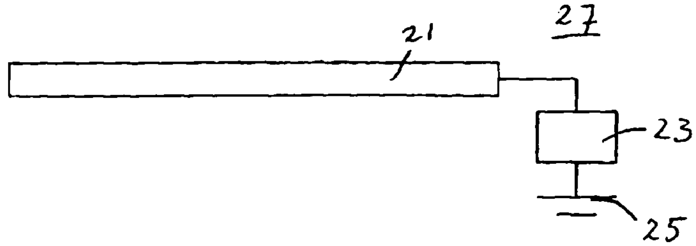

Figure 5